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Responses of Tall Fescue Cultivars to an Irrigation Gradient

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ABSTRACT

Seasonal availability of water is a major consideration in the management and selection of plant materials for irrigated pastures in the Intermountain West, USA. Objectives were to evaluate the forage yield of 10 tall fescue (*Festuca arundinacea* Schreb.) strains and cultivars across five irrigation levels and to elucidate the effects of the endophytic fungus *Neotyphodium coenophialum* (Morgan-Jones & Gems) Glenn, Bacon & Hanlin on productivity and trends. A line-source irrigation system was used in a 2-yr study. Significant differences were detected among the tall fescue entries for dry matter yield (DMY), and differences were relatively consistent across water levels (WL) as indicated by the nonsignificant cultivar × WL interaction and significant correlations among WL. Trends in DMY across WL were largely curvilinear; however, linear trends were much more predominant during the late summer and fall. Stability parameters, based on regression of cultivar × WL × year means on their respective WL × year means, differed among cultivars in analyses including all harvests but were relatively uniform ($b \approx 1.0$) for most cultivars later in the season. Differences in DMY between 'Ky 31' tall fescue infected with the *Neotyphodium* endophyte and its endophyte-free counterpart confirms earlier reports of the positive effect of this fungal organism on forage yield in tall fescue, particularly in water-limited environments. Seasonal distribution of yield was primarily determined by water availability during the late summer and fall. The relative consistency in DMY of the cultivars across WL indicates that annual yield averaged across levels of water stress would be a logical criterion for selection of germplasm for irrigated pastures in the Intermountain Region.

Federal land policies have curtailed the use of public lands for livestock grazing in the Semiarid West, particularly in the Intermountain Region. This has led to an increased interest in upgrading privately owned pastures through more intensive management and use of improved cultivars of perennial grasses. Essentially no breeding work has been done to develop grass cultivars for irrigated pastures in the western USA. In response to the need for grasses that are better adapted to these unique environmental conditions, the USDA-ARS has initiated a breeding program to develop cultivars of tall fescue for western irrigated pastures.

Tall fescue was introduced from Europe in the mid-1800s. Following its rapid expansion during the 1940s through the 1960s, it became the predominant cool-season perennial grass in the USA. It is particularly popular in the transition zone between the adaptative areas of cool-season and warm-season grasses (Sleper and West, 1996). Much of the popularity of tall fescue can be attributed to its adaptation to a wide range of soil, climatic, and management conditions.

Tall fescue is a hexaploid ($2n = 6x = 42$) and cross-fertilizing grass. Early breeding programs were based on isolation of selected accessions or naturalized populations. The release of two cultivars—Ky 31 and Alta—were instrumental in the early expansion of the species (Buckner et al., 1979; Cowan, 1956). Subsequent breeding programs in the public and private sectors have emphasized recurrent selection involving the application of various forms of progeny testing (Asay et al., 1979; Sleper, 1985; Sleper and West, 1996), and several forage and turf cultivars have since been released (Alderson and Sharp, 1994).

Animals grazing or fed tall fescue may suffer from a number of disorders including fescue foot, fat necrosis, and fescue toxicosis (Schmidt and Osborn, 1993), and there is evidence that the alkaloid ergovaline is responsible for many of these disorders (Stuedemann and Thompson, 1993). An endophyte, classified as *Neoty-*

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phodium coenophialum (Morgan-Jones & Gems) Glenn, Bacon & Hanlin has been identified with the fescue toxicity syndrome (Bacon et al., 1977; Bacon, 1995). The detrimental effects of the endophyte on the grazing animal have been confirmed in several studies including those by Hoveland et al. (1983). Shelby and Dalrymple, (1987) estimated that 90% of the tall fescue pastures in the USA were infested to some degree with the endophyte. Beef losses attributed to this fungus in tall fescue forage exceed more than $600 million annually (Hoveland, 1993).

The presence of the endophyte has now been associated with many of the positive attributes of tall fescue, including its wide adaptation and tolerance of biotic and abiotic stress (West and Gwinn, 1993). Tall fescue infected with the endophyte is reported to be more persistent than endophyte-free types in heat-stressed environments such as the Ozarks (West et al., 1988), Coastal Plains (Joost and Coombs, 1988), and the southern Piedmont (Hill et al., 1991). Procedures involved in breeding endophyte-free cultivars are discussed by Pedersen and Sleper (1988), and several endophyte-free cultivars of tall fescue have now been released. Progress has been made to develop forage-type cultivars containing endophytes that contribute to drought and pest resistance but have little or no toxic effects on the grazing animal (West et al., 1998).

Water for irrigation is limited in much of the West, particularly during the late summer. Cultivars developed for this region must, therefore, maintain an adequate level of production during periods of drought and be able to respond to more favorable conditions when water becomes available. If progress is to be made in breeding tall fescue cultivars that are better adapted to these environmental conditions, an understanding of the genetic responses to varying degrees of water stress must be obtained.

A line-source sprinkler system has been used to control the amount of water applied to an experimental area (Hanks et al., 1976.). The system was modified for use in the greenhouse (Johnson et al., 1982), and the procedure was used in the greenhouse and field to evaluate the intraspecific responses of alfalfa (*Medicago sativa* L.) and the RS wheatgrass hybrid (*Elymus hoffmanni* Jensen & Asay) to different levels of water stress (Rumbaugh et al., 1984). The line-source irrigation system also was employed by Asay and Johnson (1990) in a rain-out shelter to determine the genetic variability among crested wheatgrass [*Agropyron desertorum* (Fisch. Ex Link) Schultes] progeny lines at six levels of water application.

Certain limitations must be recognized in the statistical analyses and interpretation of data from experiments obtained with the line-source irrigation system (Hanks et al., 1980). Because water levels are not imposed randomly for each plot within a replication, a valid error term is not available for testing the main effects for water levels. An error term is available for testing the effects of other treatments and their interactions with water levels, providing the treatments (cultivars, species, etc.) are randomized within replications.

Objectives were to study (i) the trends and stability in forage yield across water levels, (ii) the effect of water level on seasonal distribution of forage yield, and (iii) effects of the *Neotyphodium* endophyte on productivity and trends.

MATERIALS AND METHODS

In the present study, 10 tall fescue cultivars and strains were established in the field under a line-source irrigation system and subjected to frequent clipping under five levels of irrigation. Alta, 'Fawn', Ky 31, and 'Martin' were described by Alderson and Sharp (1994); 'Forager' by Baluch et al. (1980); 'MO-96' by Asay and Sleper (1979); 'Advance' by Easton et al. (1994); and 'HiMag' by Crawford et al. (1998). MO HD-II is an experimental line derived through selection for improved in vitro dry matter digestibility (D.A. Sleper, 1999, personal communication). Seedlots of endophyte-free and endophyte-infected Ky 31, designated as Ky 31 E− and Ky 31 E+, were obtained from Sebeco International Seeds Inc., Halsey, OR. Chemical determinations for alkaloid status of the forage confirmed that Ky 31 E+ was infected with the fungal endophyte and that Ky 31 E− and other cultivars and strains included in the study were essentially endophyte free.

The experimental plots were established at the Utah State University Evans Research Farm, approximately 2 km south of Logan, UT (41°45′ N, 111°8′ W, 1350 m above sea level). The soil type was a Nibley silty clay loam series (fine, mixed, mesic Aquic Argiustolls).

Plots, consisting of six drilled rows 15 cm apart and 15 m long, were planted perpendicular to and on both sides of a line-source irrigation pipe using a cone seeder. The seeding rate was approximately 135 seeds per linear m of row. Alleyways (1-m wide) were mowed parallel to the line source at 3-m intervals leaving five 1- by 2-m plots, each representing a different water level (WL). Segments nearest to the line source were designated as WL-1 and the most distant plots as WL-5. Plots were arranged in a modified split-plot design with four replications, two on each side of the line source. The 10 cultivars were treated as whole plots and five WL as subplots. However, because of design limitations associated with the line-source sprinkler system, water levels were not randomized within each cultivar.

Plots were irrigated uniformly as needed during the establishment year (1995), and 56 kg N ha^{-1} was applied in midsummer and again in the fall. Amounts of water received by the plots from the irrigation treatment plus natural precipitation were measured with rain gauges from June until the final harvest in 1996 and from the first harvest until the final harvest in 1997 and 1998. These amounts for WL-1 through WL-5 respectively, were 538, 434, 315, 251, and 81 mm in 1996; 886, 766, 611, 525, and 373 mm in 1997; and 817, 702, 570, 499, and 350 mm in 1998. Plots were harvested with a sickle-bar mower to an 8-cm stubble at the boot stage of plant development at the first harvest and when the height of the regrowth was 25 to 30 cm at subsequent harvests. Six harvests in 1996 and 1997 and five in 1998 were made from mid-May until late September (1997) and early October (1996 and 1998). Because a plant growth gradient was not yet established across WL in 1996, only results from 1997 and 1998 are reported. Fertilizer (56 kg N ha^{-1}) was applied prior to the first harvest and after Harvests 2, 4, and 6 in 1996 and 1997; and prior to the first harvest and after Harvests 2, 4, and 5 in 1998. Forage samples were taken from each plot and dried to a constant weight in a forced-air oven at 70°C to determine dry matter percentage. Forage yields were reported as megagrams of dry matter per hectare (DMY).

Dry matter yield was analyzed within and across years as a modified split-plot by the GLM procedure (SAS Institute

Table 1. Mean squares from analyses of variance for dry matter yield (Mg ha^{-1}) of 10 cultivars of tall fescue at five levels of irrigation within and across two yr, for data with all harvests and without Harvests 1, 2, and 3.

		All harvests			Without harvests 1, 2, and 3		
Source	df	1997	1998	1997–1998	1997	1998	1997–1998
Cultivar (C)	9	34.26**	54.63**	73.47**	10.70**	8.68**	19.22**
Water level (WL)†	4	525.23nv†	56.17nv	458.25nv	289.47nv	126.15nv	396.97nv
C × WL	36	4.15*	1.51ns	3.02ns	1.03ns	0.26ns	0.75ns
Year (Y)	1			0.17ns			916.60**
C × Y	9			15.42**			0.16ns
WL × Y	4			123.14**			18.64**
C × WL × Y	36			2.64*			0.54ns

* indicates significance at $P = 0.05$.
** indicates significance at $P = 0.01$.
† No valid F test for WL.

Inc., 1994). Because WL were not randomized within cultivars (C), a valid test for the main effect due to WL was not available. The WL × C interaction was tested with the replication (R) × WL × C interaction. Data from individual years were treated as repeated measures in the analyses combined across years. Mean separations were made on the basis of the Fisher's protected least significant difference (LSD) at the 0.05 level of probability. Linear, quadratic, and cubic trends of DMY across WL were determined for each cultivar using orthogonal polynomials with unequal intervals (Gomez and Gomez, 1984, p. 230). Amount of water received at each WL was used in the computation of the coefficients.

Stability parameters were determined by regressing the cultivar means for specific environments, i.e., cultivar × WL × year means, on the corresponding environmental means, i.e., WL × year means (Eberhart and Russell, 1966). Computations of the environmental means did not include the value for the cultivar involved in its respective regression analysis.

RESULTS AND DISCUSSION

Significant ($P < 0.01$) differences were found among the tall fescue cultivars for DMY in 1997, 1998, and in the combined analysis across years (Table 1). Annual

Table 2. Mean forage yield, orthogonal trends, and stability parameters of 10 tall fescue cultivars and strains grown under five irrigation levels in 1997–1998, all harvests.

	Dry matter yield (Mg ha^{-1})										
	Water level						Orthogonal trends†			Stability‡	
Cultivar	1	2	3	4	5	Mean	Linear	Quadratic	Cubic	b	s_d^2
Advance	21.2	21.3	22.5	20.3	15.4	20.1	52.2**	42.3**	2.6ns	1.11	0.17
Alta	22.6	22.4	22.4	20.4	16.1	20.8	73.6**	24.4**	0.8ns	1.21	0.09
Fawn	22.4	24.1	22.5	21.5	17.9	21.7	64.4**	33.3**	1.7ns	0.85	0.15
Forager	23.8	24.0	23.8	20.1	17.7	21.9	77.1**	14.2*	1.6ns	1.17	0.19
Himag	21.1	20.0	20.0	19.1	15.3	19.1	78.7**	15.5*	5.5ns	0.89	0.09
Ky31 E+	22.9	22.4	21.9	20.7	17.6	21.1	85.2**	13.7*	0.7ns	0.98	0.10
Ky31 E−	21.7	21.4	21.6	19.1	14.9	19.8	73.8**	23.0**	0.0ns	1.17	0.09
MO_96	19.9	21.0	20.6	19.2	15.3	19.2	59.1**	40.7**	0.0ns	0.82	0.15
MO_HDII	20.2	19.4	18.8	17.6	15.0	18.2	91.0**	8.1ns	0.5ns	0.76	0.08
Martin	23.1	24.0	24.0	21.7	18.8	22.3	61.8**	34.8*	0.6ns	0.91	0.21
Mean	21.9	22.0	21.8	20.0	16.4	20.4					
LSD (0.05)	ns	2.7	2.5	2.1	2.1	1.9					

* indicates significance at $P \leq 0.05$.
** indicates significance at $P \leq 0.01$.
† Percent of WL sums of squares due to linear, quadratic, and cubic trends, based on orthogonal polynomials.
‡ Stability parameters based on regression of cultivar × WL × year means on respective WL × year means.

Table 3. Mean forage yield, orthogonal trends, and stability parameters of 10 tall fescue cultivars and strains grown under five irrigation levels in 1997–1998, without the first three harvests.

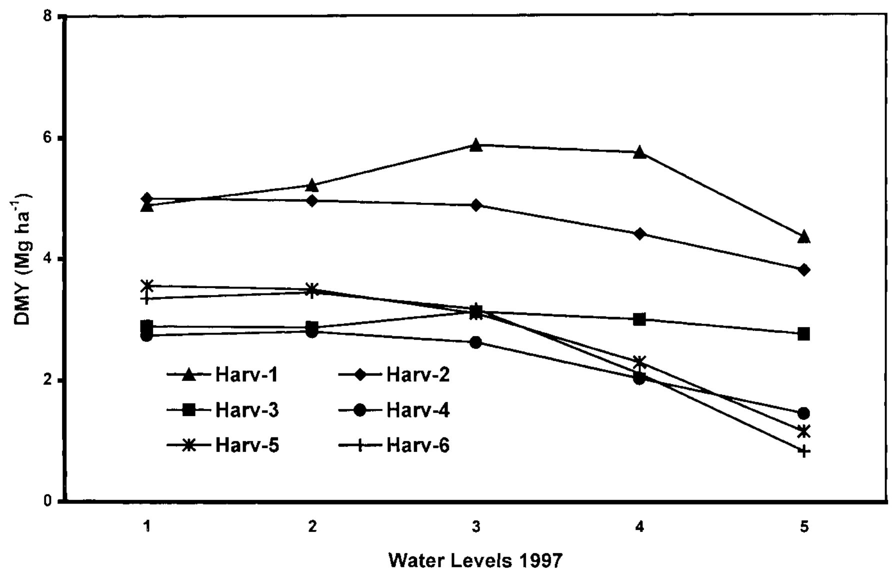
	Dry matter yield (Mg ha^{-1})										
	Water level						Orthogonal trends†			Stability‡	
Cultivar	1	2	3	4	5	Mean	Linear	Quadratic	Cubic	b	s_d^2
Advance	8.5	8.4	8.0	5.9	3.1	6.8	81.4**	16.4**	0.1ns	1.05	0.03
Alta	8.1	7.8	6.6	5.1	2.6	6.0	92.8**	6.6**	0.2ns	1.03	0.06
Fawn	8.2	8.4	7.4	5.6	3.0	6.5	86.1**	12.6**	0.6ns	1.01	0.03
Forager	7.9	8.4	7.9	5.2	3.1	6.5	76.8**	16.7**	2.1ns	1.03	0.07
Himag	7.7	6.7	6.3	5.2	2.3	5.6	88.8**	8.8**	1.8*	0.91	0.05
Ky31 E+	8.2	7.9	6.9	5.5	2.5	6.2	88.8**	10.9**	0.0ns	1.02	0.04
Ky31 E−	7.2	6.9	6.4	4.3	1.9	5.3	88.5**	11.1**	0.2ns	0.96	0.03
MO_96	6.9	6.9	6.5	4.8	2.4	5.5	81.2**	16.7**	0.0ns	0.90	0.04
MO_HDII	7.3	6.9	5.8	4.5	2.0	5.3	93.0**	6.7**	0.0ns	0.96	0.06
Martin	9.4	9.3	8.9	6.1	3.4	7.4	81.7**	13.9**	0.5ns	1.13	0.05
Mean	8.0	7.7	7.1	5.2	2.6	6.1					
LSD (0.05)	1.3	1.3	1.3	0.8	0.7	0.8					

* indicates significance at $P = 0.05$.
** indicates significance at $P = 0.01$.
† Percent of WL sums of squares due to linear, quadratic, and cubic trends, based on orthogonal polynomials.
‡ Stability parameters based on regression of cultivar × WL × year means on respective WL × year means.

DMY of the cultivars averaged across years was 21.9, 22.0, 21.8, 20.0, and 16.4 Mg ha^{-1} for WL-1 through WL-5, respectively (Table 2). Although this is an apparent curvilinear response, the trends were not consistent across harvest dates (Fig. 1). Dry matter yield of the cultivars was relatively stable across WL at the first three harvests during both years. This can be attributed to higher than average precipitation during the spring and early summer of both years. Also, N may have accumulated in the soil at the drier WL because of a reduced rate of leaching. However, in the remaining harvests of both years a significant decline in DMY across WL is evident (Fig. 1). Accordingly, trends in DMY without the inclusion of Harvests 1, 2, and 3 also were evaluated. The decline in DMY across WL was much more apparent in the analyses of data without the first three harvests. Dry matter yields for the five WL in this data set averaged across years and cultivars were 8.0, 7.7, 7.1, 5.2, and 2.6 Mg ha^{-1} (Table 3).

The cultivar × WL interaction was nonsignificant in 1998 and in the analysis combined across years when all harvests were considered. This interaction was not significant in either year or in the combined analysis across years when data from the first three harvests were excluded (Table 1). For example, the cultivars Martin, Forager, Fawn, and Ky 31 E+ were among the top yielding cultivars at all five water levels in both instances, and Ky 31 E−, MOHD-II, MO-96, and Hi-Mag were consistently in the lower yielding tier of entries (Tables 2 and 3). The relative consistency of differences among cultivars across WL is confirmed by the inter WL correlation matrices (Table 4). Correlation coefficients (r) among WL, computed from cultivar × WL means, ranged from 0.72 to 0.91 in the data involving all harvests and from 0.83 to 0.94 when the first three harvests were not included. All r values were significant ($P < 0.05$ or 0.01, $n = 10$).

It is noteworthy that DMY for Advance averaged



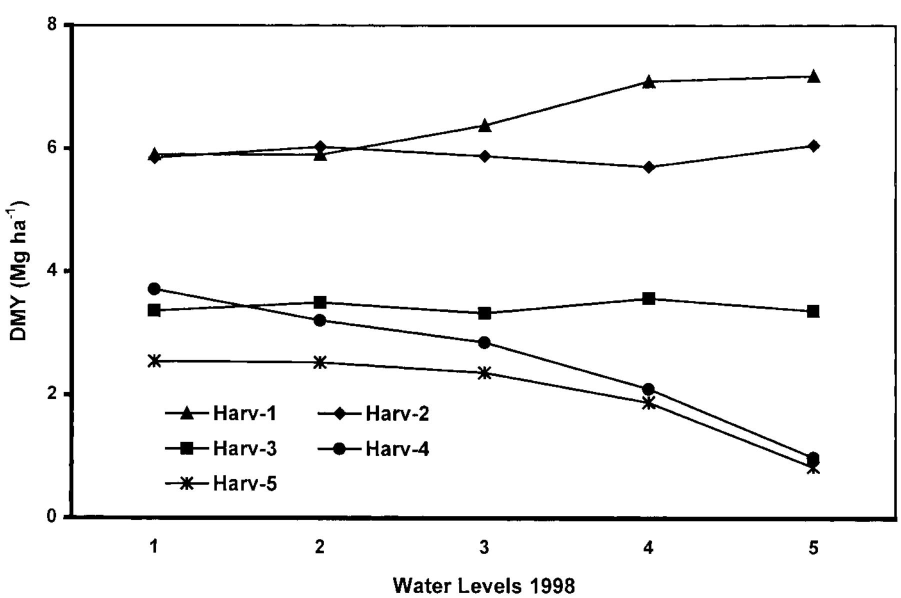


Fig. 1. Trends in dry matter yield of 10 tall fescue cultivars on six harvest dates across five water levels, 1997 and 1998.

Table 4. Correlations (r) for DMY of 10 tall fescue cultivars among five WLs, based on cultivar × WL means from data with all harvests (above diagonal) and without Harvests 1, 2, and 3 (below diagonal).

	WL				
WL	1	2	3	4	5
1		0.85**	0.84**	0.72*	0.81**
2	0.91**		0.91**	0.87**	0.89**
3	0.83**	0.94**		0.85**	0.75**
4	0.90**	0.85**	0.85**		0.83**
5	0.84**	0.93**	0.93**	0.90**	

* indicates significance at $P \leq 0.05$, $n = 10$.
** indicates significance at $P \leq 0.01$, $n = 10$.

110% of the mean in the analyses of data without the first three harvests (Table 3). However, when only the first three harvests were considered, comparative DMY for Advance was substantially less at 94% of the mean. This reflects the productivity of Advance during the late summer and fall under these environmental conditions.

Both linear and quadratic trends were significant in the analysis of data with and without Harvests 1, 2, and 3 (Tables 2 and 3). However, linear trends were more predominant in the latter. The linear sums of squares ranged from 93% of the WL sums of squares for MO HD-II and Alta to 77% for Forager, 81% for MO-96, and 82% for Martin when the early-season data were not included in the analyses. The quadratic response of the latter three entries was associated with a relatively stable forage yield across the first three WL followed by a relatively sharp decline thereafter (Fig. 2).

Stability parameters, based on regression analyses, have been used to evaluate the performance of cultivars across a series of environments (Eberhart and Russell, 1966). Stability has been defined as uniform perfor-

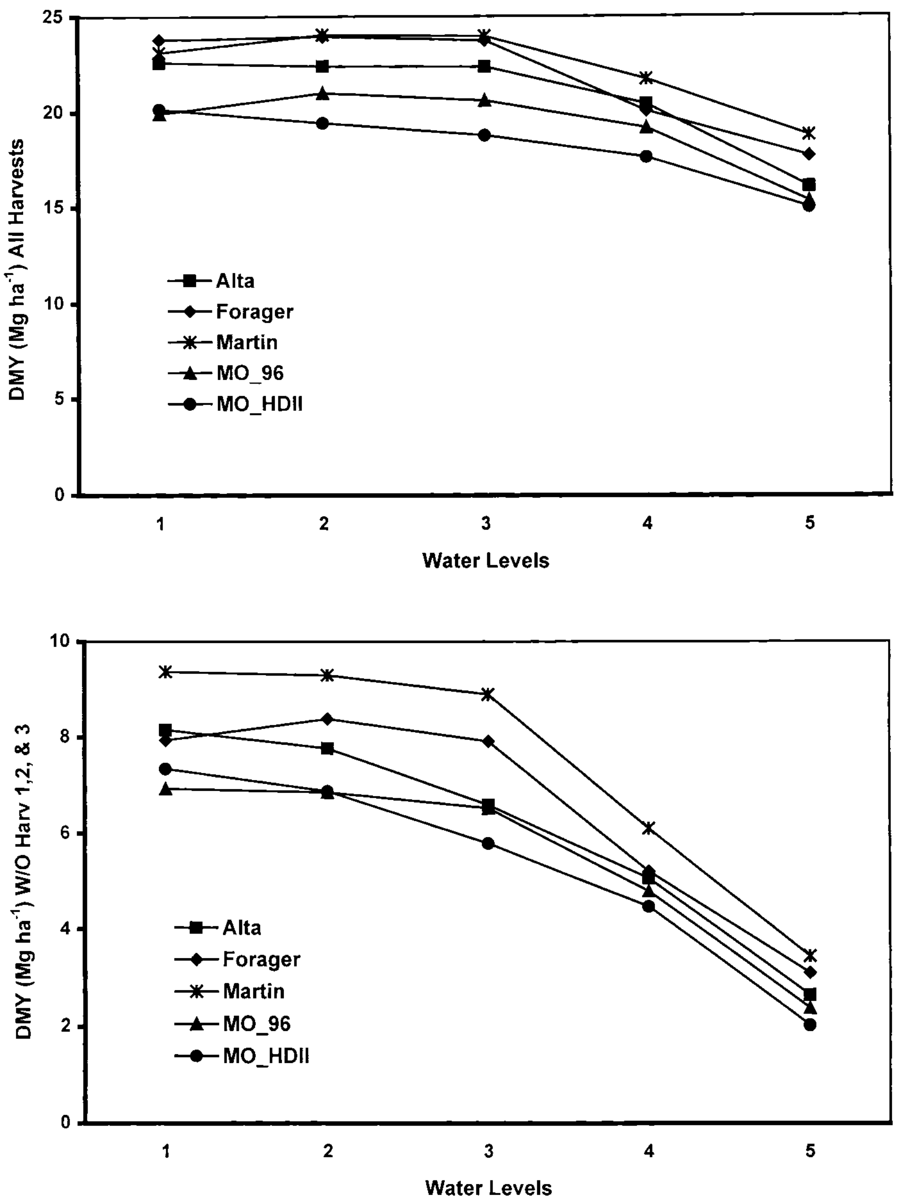


Fig. 2. Trends in dry matter yield of five representative tall fescue cultivars across five water levels, with all harvests (upper), and without Harvests 1, 2, and 3 (below), 1997–1998.

mance across a wide range of environments. A stable cultivar under this definition would perform relatively well under adverse conditions but would not improve substantially in more optimum environments. Such a cultivar would have a regression coefficient (b) across environments less than 1.0 and may be well suited for Intermountain sites where water is likely to be limited for much of the growing season, usually during the late summer and fall. Many Intermountain pasture lands have adequate water throughout most of the growing season but water deficits may periodically occur. A logical breeding objective for this scenario would be to develop cultivars with a high mean DMY, a b value of 1.0, and a low standard deviation from regression.

When all harvests were considered, Martin, Forager, Fawn, Ky 31 E+, and Alta all had relatively high annual DMY (Table 2), although the stability (b) of these cultivars across environments varied substantially. For example, the b value and standard deviation were 0.91 and 0.21 for Martin and 0.85 and 0.15 for Fawn. The b values for Alta and Forager were 1.21 and 1.17, respectively. Trends in DMY for Ky 31 E+ approached Eberhart and Russell's definition of a stable cultivar with a b value of 0.98, and a standard deviation of 0.10.

In analyses of data excluding the first three harvests, not only were the trends across WL much more pronounced, but the b values of most cultivars were closer to 1.0 and the standard deviations much smaller than in the analyses comprising all harvests (Table 3). With this scenario, selection on the basis of DMY would be a reasonable approach. It should be noted that DMY of Martin was consistently high across WL in both sets of data (Fig. 2).

Dry matter yield of Ky 31 E+ was consistently higher

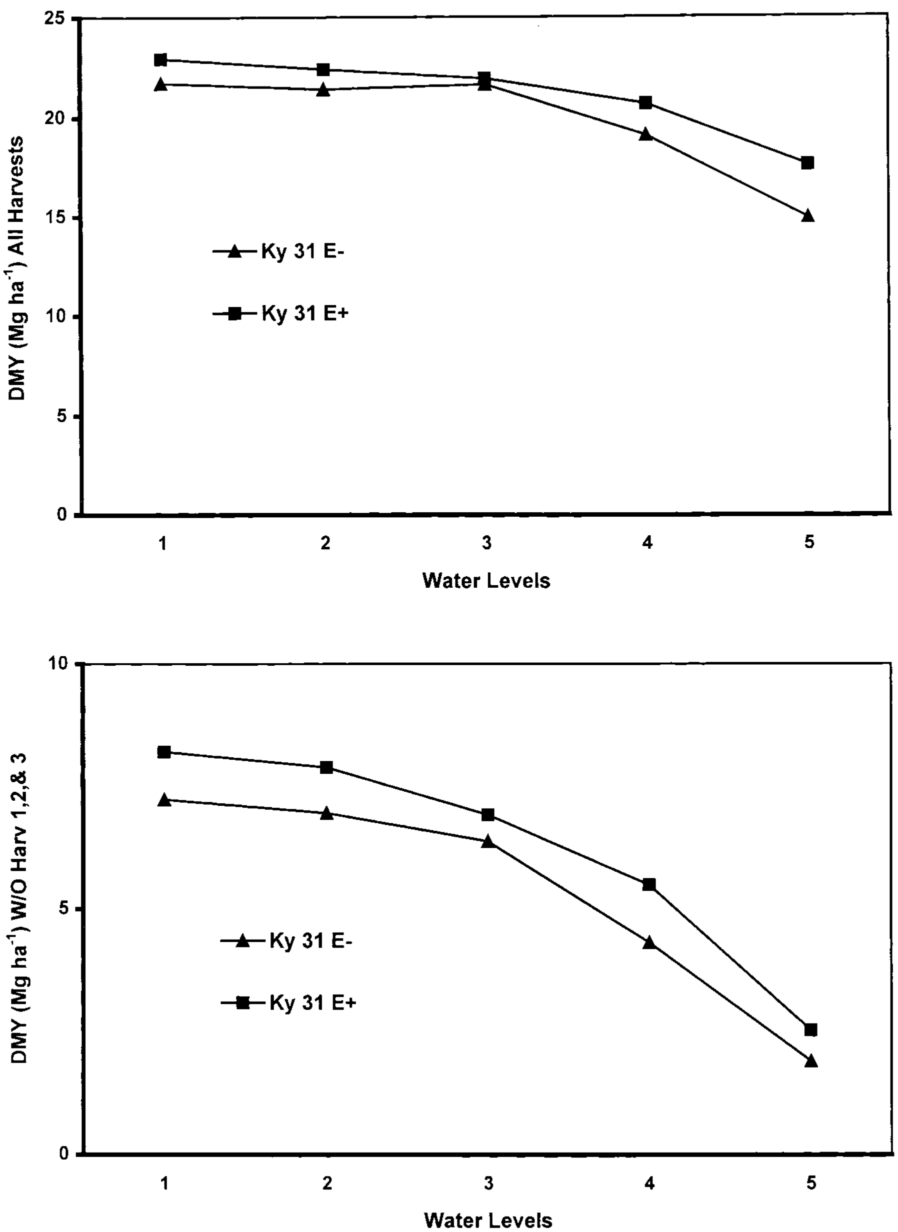


Fig. 3. Trends in dry matter yield of endophyte-free (E−) and endophyte infected (E+) Ky31 tall fescue across five water levels, with all harvests (above) and without the first three harvests (below).

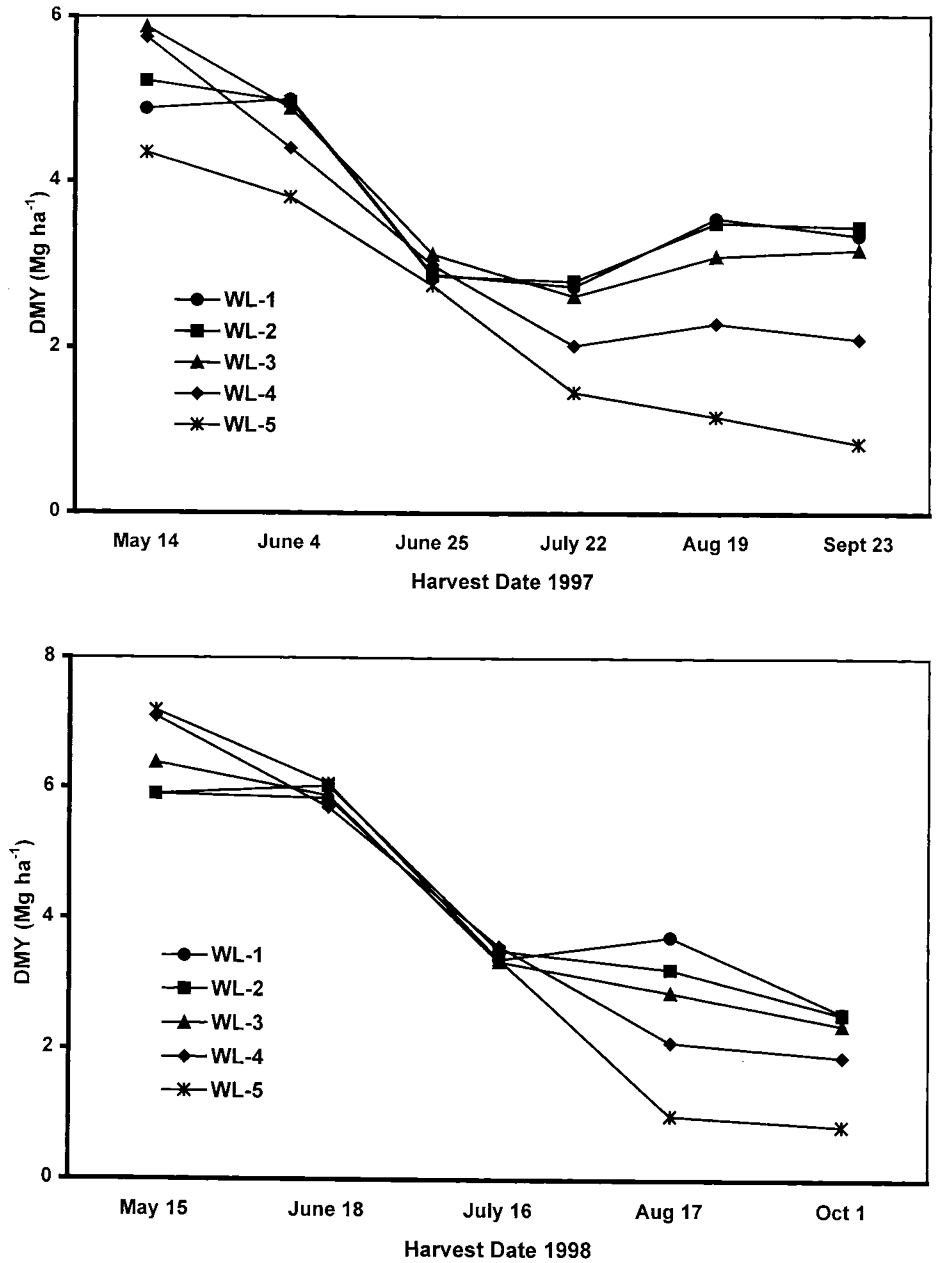


Fig. 4. Trends in dry matter yield of ten tall fescue cultivars across six harvest dates in 1997 and 1998.

than Ky 31 E− in the analyses of data with and without the first three harvests (Fig. 3). Differences were significant ($P < 0.01$) at WL-5 for annual DMY and at WL-4 in the analysis without the first three harvests. In the latter analysis, the difference between the two entries approached significance ($P = 0.057$) at WL-5. Although this relationship needs additional study, our results suggest that the presence of the *Neotyphodium* endophyte may have a beneficial effect on the productivity of tall fescue in the Intermountain Region, particularly as water becomes limiting.

Seasonal distribution of yield is an important consideration in the selection of grass germplasm for irrigated pastures. In these studies, trends in DMY across the six harvest dates in 1997 and five harvests in 1998 was associated with the amount of available water, particularly during the late summer and fall (Fig. 4). The tall fescue cultivars produced significantly ($P < 0.01$) less forage at WL 4 and 5 than all other WL at the final three harvests in 1997 and at the final two harvests in 1998. Moreover, DMY at WL 5 was significantly less than WL 4 during the late summer and early fall (Table 3).

CONCLUSIONS

Dry matter yield of the 10 tall fescue cultivars differed significantly (0.01), and responded in a curvilinear manner to five levels of irrigation. However, the trends in DMY across WL were not consistent among the six harvest dates in 1997 and the five harvests in 1998. Because of above average precipitation during spring and early summer, DMY did not decline at the drier WL until after the first three harvests in both years.

Differences among cultivars were relatively consistent across WL as indicated by the generally nonsignificant cultivar × WL interactions and significant ($P <$ 0.05 and 0.01) correlations among DMY produced at the different WL treatments. Linear and quadratic trends across WL, computed on the basis of orthogonal polynomials, were both significant; however, linear trends were much more pronounced in the analysis of data without the first three WL. Stability parameters, based on regression of cultivar means on their respective year × WL means, varied according to cultivar. When data from the first three harvests were removed, *b* values for most entries were close to 1.0.

The cultivar Ky 31 infected with the *Neotyphodium* endophyte consistently produced more DMY than its endophyte-free counterpart. Although these differences were not always significant ($P < 0.05$), the trends indicate that the endophytic fungus may have a positive effect on DMY of tall fescue in the Intermountain Region, particularly as water becomes limited.

On the basis of the stability indices and the relative consistency in DMY of the cultivars across WL in these studies, we conclude that annual yield averaged across levels of water stress would be a logical criterion for selecting germplasm for irrigated pastures in the Intermountain Region.

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